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Articles submitted for publication to the JOURNAL OF SEDIMENTARY PETROLOGY should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 1, PP. 3–17, FIGS. 1–6, TABLES 1, 2, APRIL, 1937

THE SEDIMENTS OF BARATARIA BAY

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ABSTRACT

Ninety-eight bottom samples were collected from Barataria Bay, on the margin of the Mississippi delta, in accordance with a predetermined grid pattern. Mechanical analyses were performed, and the several statistical constants of the samples computed. Maps were prepared showing the areal distribution of the samples in terms of their average size, and their "degree of sorting"; this distribution was related to the currents within the bay. In all, five main types of sedimentary curves were found, which displayed a regular variation in character from deeper to shallower parts of the bay.

INTRODUCTION

Present trends in sedimentary petrology involve the study of related series of samples, so chosen that the areal variations within a deposit may be studied. This is perhaps best accomplished with a set of samples collected approximately on a grid pattern spread over the area, so that the requirements of random sampling may be satisfied in part at least. From the analytical data obtained from such a study, it is possible to indicate on maps such attributes as the size characteristics, the degree of sorting, heavy mineral frequencies, shapes of particles, surface textures, or even mass properties such as specific gravity, color, organic content, and so on. In short, whatever attributes may be expressed as continuous variables may be plotted on isopleth maps, and each map will disclose the areal variation of the attribute considered. From such composite data it should be possible to gain an insight into the environment of deposition and the factors involved in forming the sedimentary deposit.

A program as ambitious as this would not only require considerable effort, but sound techniques as well, so that reliable data may be obtained. There can be little question, however, that such an approach would afford more pertinent data than incidental studies that are often made of formations, in the hope that the analyses will afford some clue, for example, of whether the sediment may be correlated from point to point. Indeed, from a comprehensive study of all the factors that can be evaluated, such applied problems as correlation will be automatically solved, in terms both of their possibilities and limitations.

The present study is an approach toward an evaluation of the environment of deposition in a tidal lagoon: Barataria Bay, at the edge of the Mississippi delta. The present paper describes the area, furnishes data about the samples, and considers the

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size attributes of the samples. It is the forerunner of similar papers on the heavy mineral content and the organic content of the sediments, studies which are in progress as this paper is published.

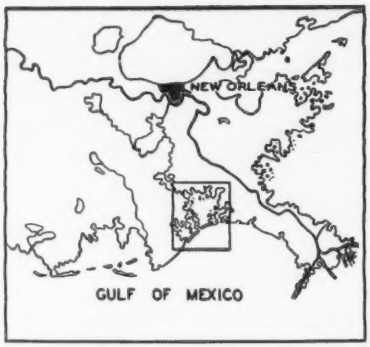

FIG. 1.—Map of part of the Mississippi delta, showing, in the small rectangle, the area under discussion.

With the exception of a single report, there appears to be no previous detailed study of Barataria Bay. The exception is a Master's thesis by Miss Mattie Winston, in the Department of Geology of the University of Cincinnati. Miss Winston collected 30 random samples of bottom muds and sands from an area larger than that included in the present paper. The samples were examined from the points of view of detailed mechanical analyses, color analysis, carbonate analysis, and the like. The data are ably presented, and the writers concur in Miss Winston's conclusions, which will be mentioned later.

Barataria Bay was visited by both authors of this paper; the samples were collected by the junior author. The analyses were performed jointly, and the assemblage of the material into forms of presentation is largely the responsibility of the senior author. Both writers wish to acknowledge their indebtedness to Dr. Elinor H. Behre, Director of the Louisiana State University Marine Biological Laboratory, whose helpful cooperation made possible the collection of the samples; and to Dr. W. H. Bucher, of the Department of Geology of the University of Cincinnati, for his kindness in sending Miss Winston's thesis to the writers.

DESCRIPTION OF THE SAMPLING LOCALITY

Barataria Bay lies about 50 miles south-southeast of New Orleans, Louisiana. The Mississippi River channel lies about 10 miles east of the bay proper. A canal joins river and bay near New Orleans; other than this no streams enter the bay. Figure 1 indicates a portion of the Mississippi delta, and locates the area under consideration.

The bay itself may be described as a tidal laggoon, with a main passage (Barataria Pass) about one-fourth of a mile wide, opening southward into the Gulf of Mexico. Two smaller passes (Pass Abel and Pass Justin) have recently opened through the barrier, and a small delta is rapidly being built in a projecting southeasterly arm of the main bay, from sediments washed through the passes during storms on the Gulf. The main bay itself is a rectangle slightly wider at the north than at the south, and the east, west, and north shores of the bay are a series of islands rather than mainland. Several small islands interrupt the surface of the bay, and many slightly submerged oyster reefs are to be found here and there.

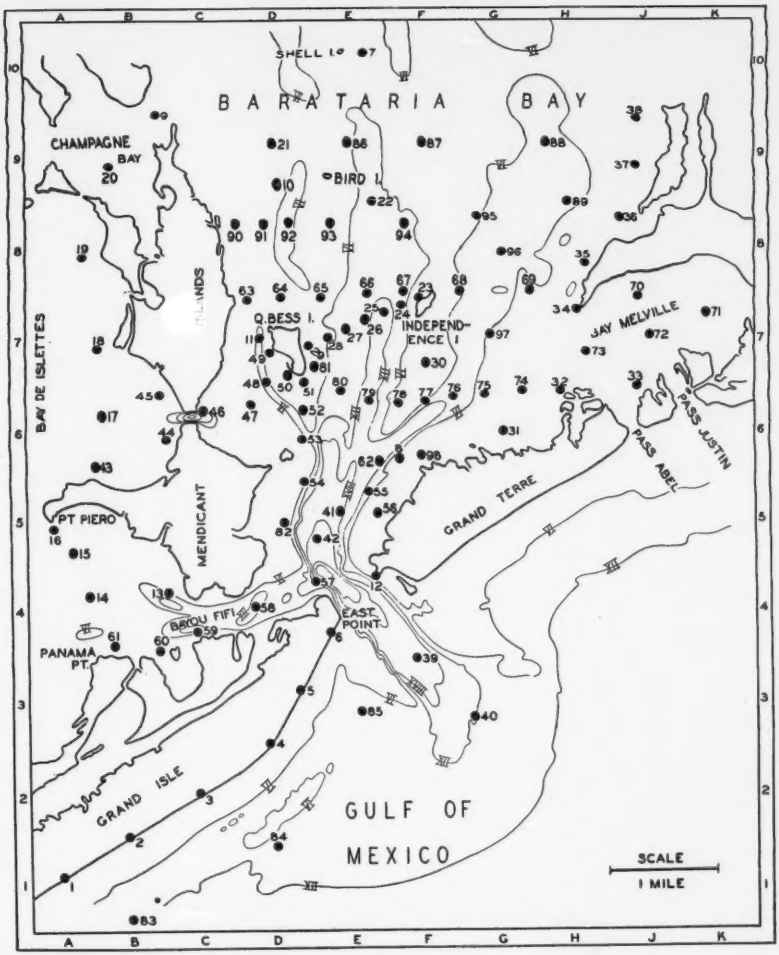

FIG. 2.—Map of the southern part of Barataria Bay, showing the locations of samples, and depth contours. The Roman numerals refer to depth in feet.

The present study is based on 98 samples collected in the bay and its immediate vicinity. Two other samples, collected farther out in the Gulf, were used merely as additional random samples, but are not included on the maps. The sampling within the bay proper was confined to its southern portion, where presumably the greatest variations are

to be expected in the sediments. Figure 2 is a map of this portion of the bay, showing the sampling localities, each identified by the sample number; in addition, several sounding lines are included, to show the variations in depth of the bay, as well as the main channels.[1] For the most part the bay is quite shallow, depth varying from 1 to 4 or 5 feet. In the central portion of the bay, however, is a channel from 6 to 18 feet deep, extending from Barataria Pass (at East Point) to the northern confines of the present area. Indeed, just within the pass itself, the greatest depth is 165 feet, attesting to the strength of the currents that surge into and out of the bay. The channel extends outward into the Gulf itself, and terminates in a broad delta-like extension, as shown by the outermost depth contour on the map. The two new channels to the east (Abel and Justin) show no such scouring, in accordance with their recent formation.

Some of the relations between the depth chart and the distribution of sediments in the bay will receive consideration below. As for the samples themselves, they are numbered serially in the order of collection, and at first glance are spread at random over the bay. A grid pattern was used as a control in sampling, however, such that every square mile was divided into quarters. Samples were collected from nearly every quarter, and on this basic pattern additional samples were collected, when indications were seen of changes in the nature of the samples. Within the limitations of practical work, the grid served excellently as a primary control of sampling operations.

During the collection of the samples, bearings were taken by rough triangulation, using islands, Barataria Light, and channel lights as markers. A small motor boat was used for most of the collecting, and samples were obtained either with an oyster rake (in depths from 3 to 9 feet) or with a clam shell snapper in deeper water. Depth of water was noted in each case; the samples ranged in size from about 100 to 500 grams. They were preserved in double-weight Kraft paper bags, which proved quite satisfactory in avoiding losses. For the most part the samples are dark-colored, classified in the field as sandy muds. Numerous shell fragments are present in many samples; the bearing of these on the analyses will be treated below.

It is worthy of note that with a single exception, no storms interrupted the work of collecting the samples. Between the collection of samples 61 and 62 occurred a storm which delayed work for three days, but as far as the analyses showed, this had no serious effect on adjacent samples separated by the storm interval. As a general rule, however, it seems advisable to collect a suite of samples during a quiet interval, so that if conditions within the lo-

[1] It was a fortunate coincidence that at the time the samples were collected, the U. S. Coast and Geodetic Survey was sounding the bay. Photostats of this survey (Hydrographic Survey No. 5492, 1933–34) were obtained, and the present figure constructed from them.

cality are changing rapidly, no serious disagreements enter the completed picture. One should, perhaps, consider a series of samples collected within a given short interval as furnishing an instantaneous picture of the environment. Thus the sampling process should not be extended unduly, at least with respect to recent sediments in their environment of deposition.

ANALYSIS OF THE SAMPLES

The pipette method was used in the analysis of all samples except a half dozen whose particles lie entirely within the range of sieve sizes. A standardized procedure was used, involving the crushing and quartering of the air-dried samples, and the use of a test sample weighing from 20 to 25 grams for the analysis. The test sample was disaggregated by rubbing with the fingers or with a stiff brush in N/100 sodium oxalate solution, and dispersion was completed by heating the suspension to the boiling point. After cooling, the suspension was passed through a sieve with meshes of 0.061 mm., to separate the sand. The finer material was pipetted, the dried sand was sieved, and the two parts of the analysis combined into a single table of percentages. The detailed steps involved in such analyses are described elsewhere (1).

In obtaining the analytical data, the samples were pipetted at each Wentworth grade interval from 1/32 to 1/1024 mm., and in the steep parts of the curve intermediate points were determined for the closer approximation of median and quartiles. In sieving, also, intervals based on $\sqrt{2}$ or $\sqrt[4]{2}$ were used where necessary to avoid large classes. On the average from 10 to 12 points were determined for each curve.

Several factors entered the analyses which in some cases interposed difficulties. Thus, the amount of organic matter increased in the finer sediments, and this material (in part soluble) tended apparently to flocculate the suspensions. Even in the coarser sediments the organic matter had an influence on the analysis of the finer sizes. A pragmatic attitude was adopted, however. Where the data did not depart too widely from analyses of similar unflocculated samples, the data were accepted. In some cases duplicate analyses were run as a check on the results. When flocculation occurred during pipetting, only partial analyses were run. The practice was to continue pipetting until traces of incipient flocculation[2] appeared, which fortunately occurred beyond the third quartile in nearly every case where flocculation took place. Thus from the point of view of median and quartiles, flocculation was no problem, but it seriously interfered with the computation of moments, as will be pointed out below, because of the open ends on such curves.

Many of the samples contained shells and shell fragments, and it was not always simple to decide whether

[2] Incipient flocculation may be recognized by the appearance of a fluffy precipitate at the bottom of the jar, in contrast to the solid-appearing sediment of the coarser sizes.

TABLE 1. *Size frequency distributions of samples*

Sample	Percentages in Phi Units (Wentworth Grades)										Type	(Md_ϕ)	(QD_ϕ)
	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	>10			
1	0.6	70.2	29.2								I	2.80	0.21
2	1.0	69.9	29.1								I	2.82	0.22
3	0.8	73.7	25.5								I	2.80	0.21
4	0.9	75.3	23.8								I	2.80	0.20
5	0.6	62.5	36.9								I	2.88	0.22
6	1.1	68.8	30.1								I	2.85	0.25
7	0.6	5.9	33.0	24.9	9.4	7.8	5.5	5.4	4.4	3.1	III	4.20	1.30
8	1.0	2.3	6.6	16.2	12.0	11.4	13.3	11.0	7.5	18.7	V	6.90	2.13
9	1.2	1.6	15.3	38.4	13.0	9.5	5.6	5.3	4.2	5.9	IV	4.70	1.24
10	9.5	15.8	59.0	8.4	0.9	0.9	1.4	2.3	1.8		II	3.33	0.36
11	0.4	3.9	45.2	24.7	3.7	8.1	3.0	3.8	3.0	4.2	III	4.00	0.75
12	5.6	48.4	42.7	3.3							I	2.97	0.27
13	6.3	7.5	25.4	17.2	9.5	6.7	27.4				IV	4.50	1.95
14	1.1	16.3	58.7	11.9	3.1	0.7	2.7	1.7	1.4	2.4	II	3.40	0.40
15		13.8	39.3	15.4	9.1	4.5	6.4	4.4	3.6	3.5	III	3.75	1.25
16	2.3	7.9	23.9	25.5	9.2	7.9	7.7	5.8	4.6	5.2	IV	4.40	1.58
17	3.0	6.2	30.7	25.7	9.5	7.5	6.4	4.1	3.2	3.7	III	4.28	1.17
18	1.4	5.2	22.4	29.3	8.3	8.5	4.6	20.3*			IV	4.80	1.60
19	1.0	3.1	15.2	32.0	14.3	10.0	7.2	6.0	4.8	6.4	IV	4.90	1.42
20	3.2	3.9	10.5	24.1	14.2	15.4	13.5	7.7	5.1	2.4	V	5.50	1.52
21	2.4	14.5	53.9	12.2	5.5	1.6	2.5	2.0	1.6	3.8	II	3.42	0.58
22	2.2	38.8	42.2	7.9	1.4	1.8	1.0	1.1	1.0	2.6	II	3.11	0.35
23		11.5	28.4	19.1	7.3	7.8	4.8	8.4	6.7	6.0	IV	4.46	1.80
24	2.7	7.4	48.5	19.1	5.3	3.8	3.6	3.6	2.4	3.6	III	3.84	0.64
25	0.9	5.7	41.9	20.1	6.0	5.7	5.0	4.4	3.6	6.2	III	4.03	1.23
26	1.7	6.8	41.3	16.4	5.6	6.5	6.8	4.8	3.8	6.3	III	4.00	1.51
27	1.4	7.7	50.2	17.8	2.6	5.4	3.0	3.2	3.6	6.1	III	3.75	0.67
28	1.7	30.4	44.5	11.2	3.0	1.9	2.9	1.5	1.2	1.7	II	3.30	0.52
29	4.6	19.2	31.7	16.8	6.4	5.2	5.2	3.7	2.9	4.3	III	3.70	1.15
30		12.9	43.2	21.2	6.5	6.8	2.4	3.8	1.8	1.4	III	3.80	0.79
31		40.0	32.5	3.8	4.5	6.5	2.7	4.7	3.2	2.1	II	3.14	0.83
32	0.8	7.0	31.6	21.1	10.2	9.0	6.3	4.1	3.2	6.7	IV	4.35	1.50
33	1.0	8.1	32.1	23.6	8.0	6.5	6.0	5.0	3.2	6.0	III	4.30	1.38
34	2.8	4.5	7.9	20.8	19.5	16.4	28.1*				V	5.65	1.40
35	0.5	2.1	14.0	37.2	19.9	11.4	6.1	8.8*			IV	4.91	0.90
36	0.5	2.0	7.5	37.4	20.8	9.5	22.3*				IV	5.08	1.13
37	2.1	2.1	10.7	23.6	15.1	14.0	11.8	20.6*			V	5.75	1.58
38		3.4	19.7	25.4	15.7	10.2	9.9	6.9	3.7	5.1	IV	5.07	1.53
39		37.0	45.4	7.3	3.8	3.3	3.8	3.6	2.5	3.3	II	3.30	0.65
40	0.4	4.0	38.2	28.5	6.0	4.3	4.7	4.2	3.0	5.7	III	4.15	0.94
41	1.2	14.7	25.6	17.6	6.8	5.7	8.4	20.0*			IV	4.30	1.52
42	1.5	32.2	36.5	12.5	5.1	6.7	5.5				II	3.36	0.70
43	4.4	3.1	8.9	19.9	12.0	11.4	10.8	8.1	5.9	10.5	V	5.65	1.90
44	0.5	2.6	7.2	30.0	14.9	12.9	11.2	7.8	6.5	6.4	V	5.63	1.65
45	1.4	1.9	14.4	40.2	8.5	8.4	7.1	6.6	5.2	6.3	IV	4.66	1.44
46	0.6	3.6	4.2	17.8	12.4	10.8	9.9	40.7*			V	7.05	2.23
47	0.7	8.2	27.3	32.7	7.7	5.6	4.6	4.4	4.0	4.8	III	4.44	1.03
48	0.4	3.5	18.8	29.5	11.2	10.4	7.5	6.8	4.4	7.5	IV	4.76	1.53
49	0.3	15.6	54.1	21.3	4.1	2.6	2.0				II	3.50	0.47
50	0.3	24.4	56.0	15.1	4.2						II	3.30	0.34
51	10.5	29.2	37.3	15.1	4.2	3.7					II	3.21	0.32
52	0.3	13.3	63.5	14.2	4.0	3.4	1.3				II	3.37	0.37
53	1.2	26.9	54.7	11.0	3.9	2.3					II	3.25	0.32
54	0.9	20.4	47.3	17.7	3.3	2.0	3.9	1.8	1.0	1.7	II	3.38	0.59
55	0.4	18.0	49.5	12.4	3.3	3.9	4.9	2.7	1.2	3.7	II	3.35	0.69

* Partial analyses only, due to incipient flocculation.

TABLE 1 (*Continued*)

Sample	Percentages in Phi Units (Wentworth Grades)										Type	(Md_ϕ)	(QD_ϕ)
	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	>10			
56	0.5	4.1	9.8	27.9	13.5	13.5	7.4	8.3	7.6	7.4	V	5.42	1.61
57	0.5	35.6	50.1	7.8	3.9	2.1					II	3.10	0.23
58	3.5	12.6	14.2	28.6	10.1	8.7	22.3[4]				IV	4.56	1.53
59	1.4	40.7	38.9	5.1	3.9						II	2.96	0.27
60	1.9	32.5	43.5	11.8	4.0	2.5	1.5	2.3			II	3.18	0.45
61	1.9	11.5	49.5	22.4	5.7	4.5	2.0	2.5			III	3.62	0.62
62	1.0	13.1	33.7	18.3	6.1	5.0	7.7	5.3	5.1	4.7	III	4.00	1.50
63	1.1	2.5	6.5	22.4	17.2	9.3	41.0[4]				V	6.05	1.98
64	0.4	5.1	31.8	30.3	5.4	7.8	3.0	6.4	5.6	5.2	III	4.35	1.19
65	0.7	18.3	53.2	17.2	5.6	5.0					II	3.36	0.49
66	0.5	5.9	32.2	32.7	4.9	5.4	2.7	5.2	4.6	3.9	III	4.28	0.83
67	1.4	6.2	35.1	27.5	7.3	4.9	3.1	7.6	5.5	2.4	III	4.18	1.03
68	2.8	4.3	11.1	27.8	10.3	9.3	10.5	19.8[4]			IV	5.00	1.66
69	4.2	4.7	14.2	31.7	8.7	8.0	28.5[4]				IV	4.83	1.68
70	0.7	2.3	5.2	23.2	19.4	14.1	10.1	10.0	8.7	6.3	V	5.93	1.63
71	1.1	4.9	31.1	41.9	13.9	7.8	3.7	2.4	3.7	3.4	III	4.20	0.54
72	1.1	36.1	58.4	4.4							I	3.12	0.22
73	0.2	21.8	72.8	5.2							I	3.21	0.20
74	3.4	1.6	4.4	18.0	14.7	15.3	15.1	12.6	10.3	4.6	V	6.47	1.63
75		18.9	34.4	18.3	6.6	5.6	5.1	3.9	3.2	4.0	III	3.82	1.15
76		3.3	19.0	34.7	10.6	9.9	22.5[4]				IV	4.75	1.27
77	7.9	8.5	21.0	19.9	8.9	5.9	6.3				III	3.50	1.67
78	0.9	6.9	54.0	24.2	5.3	5.3	4.9	3.8	2.1	2.7	III	3.96	0.79
79	0.9	13.6	43.9	20.1	7.2	4.8	9.5				III	3.60	0.74
80	0.3	7.4	77.4	9.4	5.5						II	3.40	0.24
81	0.9	17.5	33.9	26.8	4.0	6.9					II	3.40	0.57
82	2.9	15.5	37.0	30.3	5.1	1.9	2.2	5.1			III	3.70	0.67
83	0.8	10.2	79.2	9.8							I	3.46	0.22
84	1.0	16.3	73.8	8.9							I	3.38	0.24
85	1.8	35.7	61.9	0.6							I	2.87	0.24
86	0.9	11.2	39.7	26.8	5.0	3.7	4.6	2.6	1.6	3.9	III	3.86	0.75
87	1.6	10.4	43.9	19.4	4.4	3.3	4.3	2.3	5.3	5.1	III	3.80	1.49
88		9.5	50.3	16.7	4.9	3.3	6.2	3.7	1.0	4.4	III	3.70	0.78
89	4.4	11.0	43.2	21.8	7.1	6.4	6.1				III	3.74	0.73
90		4.1	17.6	31.1	11.4	10.2	9.7	15.9[4]			IV	4.92	1.48
91	1.3	7.2	45.2	27.8	12.0	6.5					III	3.88	0.70
92	0.8	6.3	18.2	28.0	9.1	9.7	9.9	5.6	3.1	9.1	IV	4.82	1.63
93	8.6	28.4	26.0	22.5	4.8	5.2	4.5				II	3.41	0.82
94	2.5	17.8	40.3	20.1	4.3	2.5	3.5	3.0	2.5	3.5	III	3.61	0.73
95	0.4	5.9	56.5	18.9	2.6	2.3	3.2	1.8	2.6	5.8	III	3.69	0.57
96	6.3	17.1	42.4	17.9	9.0	7.3					II	3.46	0.67
97	2.1	16.7	39.6	17.7	8.3	8.3	7.3				III	3.65	0.88
98	0.3	20.6	55.4	16.6	6.2	6.1	5.5	3.6	3.0	2.7	III	3.62	1.03

they should be included in the size distribution of the sediment. The test used was whether the shells were predominantly fragments, and whether they displayed a fairly regular size distribution. The problem of the inclusion or non-inclusion of shells in mechanical analysis deserves study in its own right.

Tests were also conducted on the possible influence of the soluble salts in the samples, but apparently they had no appreciable effect on the analyses. In similar fashion the organic content of the average sample showed no effect except in the very fine sizes. In practically every case there was some material below 1 mi-

cron in the sample, but the readings became erratic as the smaller sizes were reached. Determinations below 1 micron were not made, partly on this account, and also because usually about 95 per cent of the sample was analyzed by the time 1 micron was reached. Another factor operative here is that errors and soluble matter are likely to be grouped in the finest sizes, which affects not only the curve but also the computed statistical moments.

The results of the mechanical analyses are shown in Table 1. For economy of space the data have been assembled into Wentworth classes, expressed in phi units. In the phi notation, negative logarithms of the diameters are used (as is pointed out below), such that an arithmetic grade scale results. On this scale $1 = \frac{1}{2}$ mm., $2 = \frac{1}{4}$ mm., and so on along the usual geometric scale. Where flocculation set in during the analysis, the material in the last class mentioned in the table refers to all grains smaller than the size involved. Such cases are marked with an asterisk.

When all the samples are plotted as cumulative curves on a single sheet the figure resembles a wide dark band, with, however, several lighter zones within it. These zones roughly differentiate five types of sediments within the environment. Thus there is a band of beach sands, a band of sands with "tails" of silt, and so on, with an increased spreading out of the curves as the finer sediments are reached. Figure 3 shows the five bands of curves assembled in a single figure. The individual curves are not drawn, but the extremes of each type delineate the limits of the band, and show that

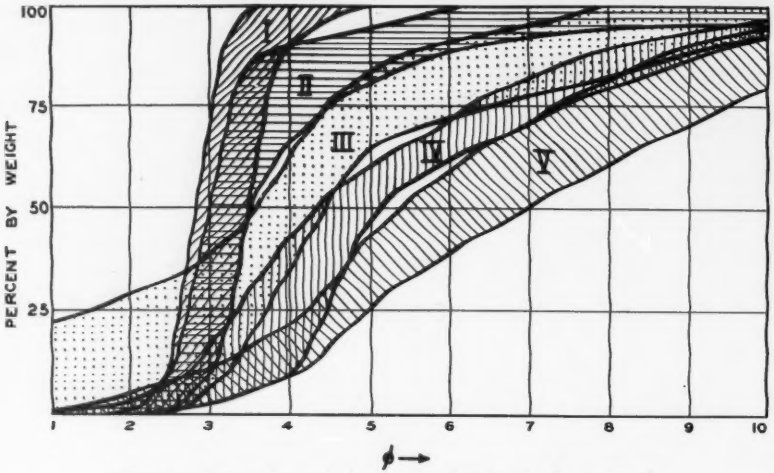

FIG. 3.—Graph of cumulative curves, showing the five types of sediments in Barataria Bay.

there is a progressive change from coarse to fine sediments in the bay.

It will be noted that the phi-scale is used along the horizontal axis of the figure. A detailed discussion of the phi-method is given elsewhere; only an outline is given here for clarity. The method depends on the use of logarithms to the base 2, which when applied to the reciprocals of the grain sizes (or used directly as negative logs of the diameters) yields a series of arithmetic values, free of the objections and inconveniences of a geometric grade scale. The numbers are so chosen that each integer on the phi scale involves one Wentworth class unit, and the numbers increase with decreasing grain size. Thus, 1 mm. is zero on the phi scale, ½ mm. is 1, ¼ mm. is 2, etc. Medians, quartiles, moments, in short, nearly any statistical value may be expressed in this notation. Once some familiarity is gained, the measures are very readily visualized, because each increase of one unit in the phi value of the average size means that the average size has been reduced by half. For the sake of consistency, the phi notation is used throughout in this paper, with equivalent diameter values where needed, to introduce the concept.

The five types of curves shown in Figure 3 may be briefly described. Type I consists mainly of beach sands and shallow water sands in the zone of breakers. These curves are quite symmetrical, as may be noted, and they are the coarsest sediments in the environment. The median values average about $\phi=3$ (diameter = ⅛ mm.). Type II curves are predominantly sandy, but they carry a "tail" of silt and clay, which renders them more asymmetrical. Samples of this type occur mainly in the principal channels within the main bay, where currents are most pronounced. The medians of these curves average about $\phi=3.3$ (diameter = 1/10 mm.). Type III curves are less steeply inclined in the central portion than the preceding types, although they contain on the average about 50 per cent of sand. Thus their medians vary about $\phi=4$ (diameter = 1/16 mm.). Samples of this type border the main channels of the bay, and locally cover large areas of bottom in waters of moderate depth. Type IV curves are predominantly silty, having on the average only about 25 per cent of sand. The medians average about $\phi=4.7$ (diameter = 0.037 mm.). Organic matter is noticeably present in these samples. Type V includes the finest sediments in the bay, with medians averaging $\phi=6$ (diameter = 1/64 mm.). Sand is present to the extent of about 15 per cent. These samples fringe the low islands in the bay, and in general lie farthest removed from currents. Their organic content, too, is usually quite large compared with other types. The distribution of the samples over these five types is shown in the last column of Table 1.

From each type of curve a single sample was chosen to illustrate more specifically the attributes of the group. The cumulative curves of these samples are shown in Figure 4, each numbered in accordance with Figure 2 and Table 1. The statistical values of these five curves are shown in Table 2, which includes the median, (Md_ϕ), quartiles, and quartile measures, (QD_ϕ, Skq_ϕ), in phi terms, as well as the phi-mean, (M_ϕ), the phi-standard-deviation, (σ_ϕ), and the phi-skewness, (Sk_ϕ),

TABLE 2. *Statistical comparison of sedimentary types*

Type	Sample	Md_ϕ	QD_ϕ	Skq_ϕ	M_ϕ	σ_ϕ	Sk_ϕ	$Q_{1\phi}$	Q_ϕ	Md in mm.	MG in mm.
I	6	2.85	0.25	+0.01	2.79	0.48	+0.34	2.61	3.10	0.139	0.145
II	52	3.37	0.37	+0.18	3.73	0.95	+0.81	3.18	3.92	0.093	0.076
III	30	3.80	0.79	+0.26	4.40	1.74	+0.80	3.27	4.85	0.072	0.048
IV	9	4.70	1.24	+0.66	5.54	2.06	+0.57	4.12	6.60	0.040	0.022
V	70	5.93	1.63	+0.45	6.37	2.10	+0.17	4.75	8.00	0.017	0.012

based on the moments of the distribution. In addition, the median and geometric mean are expressed in millimeters, for direct comparison.

An examination of the curves of Figure 4 and the data of Table 2 (Skq_ϕ and Sk_ϕ) both show that intermediate types of curves have less symmetry than either I or V. There seems to be no immediately apparent reason why the skewness behaves in this less regular manner.

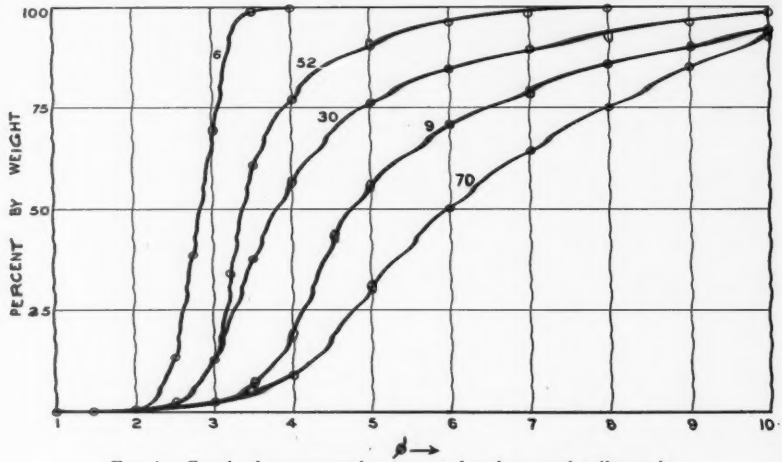

FIG. 4.—Graph of representative curves of each type of sediment in Barataria Bay. The sample numbers refer to fig. 2.

shows that in addition to a consistent change in the average size (Md_ϕ, M_ϕ, MD_ℓ, and GM_ℓ), the spread of the curves (QD_ϕ and σ_ϕ) increases as the average grain size decreases. Curiously enough, however, the asymmetry of the curves does not increase consistently through the five types. The skewness values

AREAL DISTRIBUTION OF THE SEDIMENTS

The comparative data in Table 2 indicate that the two principal sets of statistical measures, those based on median and quartiles, and those based on the moments, show results of the same general nature, although in detail they differ in absolute value.

This is because the quartile measures are based on the central 50 per cent of the distributions, whereas the moment method involves the entire range, and thus presents, perhaps, a more comprehensive value. The response to extreme cases, as represented by the "tails" of the curves, is greatest with higher moments, which accounts for the apparently large differences in the skewness values, for example, in the two sets of data.

The writers intended, in the present paper, to base the discussion on the moment measures of the curves, but a difficulty arose in its practical application. That is, a majority of the samples had a remainder of material below 1 micron in diameter, which left an open end to the curve, thus causing fluctuations in the higher moments. Experience thus shows that the moment method of analysis is most applicable to curves in which the complete analysis is available, although the first two moments are not seriously affected by such open ends in the data. These considerations influenced the writers in choosing the phi-median as the basis for a map to show the areal distribution of sediments within the environment.

The phi-median of each sample was accordingly drawn at the corresponding sampling point, and isopleths, representing one-half phi unit (one $\sqrt{2}$ class interval) were drawn through the values, as shown in Figure 5. It will be noted that the numbers are smallest toward the center of the bay, and increase toward the edges. It should be recalled that the larger the phi-value, the finer the average size; thus the value 4 is 1/16 mm., 5 is 1/32 mm., etc. This map shows a striking pattern at a glance: the central isopleths enclose linear zones, which in the main are oriented with the main channel in Barataria Pass itself. Outward from the central zone of coarsest sediments the bottom deposits are less regularly placed, but in general there is a gradation toward the shores. Consider for example the 3.50 isopleth. This line starts at the main pass, swings to the north between Independence and Queen Bess Islands, and defines a linear zone of fairly coarse material. (The value 3.50 for the median means that the average size lies between $\frac{1}{8}$ and 1/16 mm., a value within the fine sand ranges.) In addition to this channel, the 3.50 line is also to be noted within Melville Bay opposite the new pass recently cut through Grand Terre. Indeed, these coarse sediments within the smaller bay undoubtedly represent a delta of sand being built into the bay by material washed through the pass during storms. The greater part of the main bay in the area studied, however, has sediments ranging in median size from 3.50 to 4.00, and near the shores of the bay the isopleths rapidly increase in value, attesting to the decreasing grain size. This decrease is most noticeable along the west edge of the main bay. Furthermore, there is a projection of fine material along the western edge of

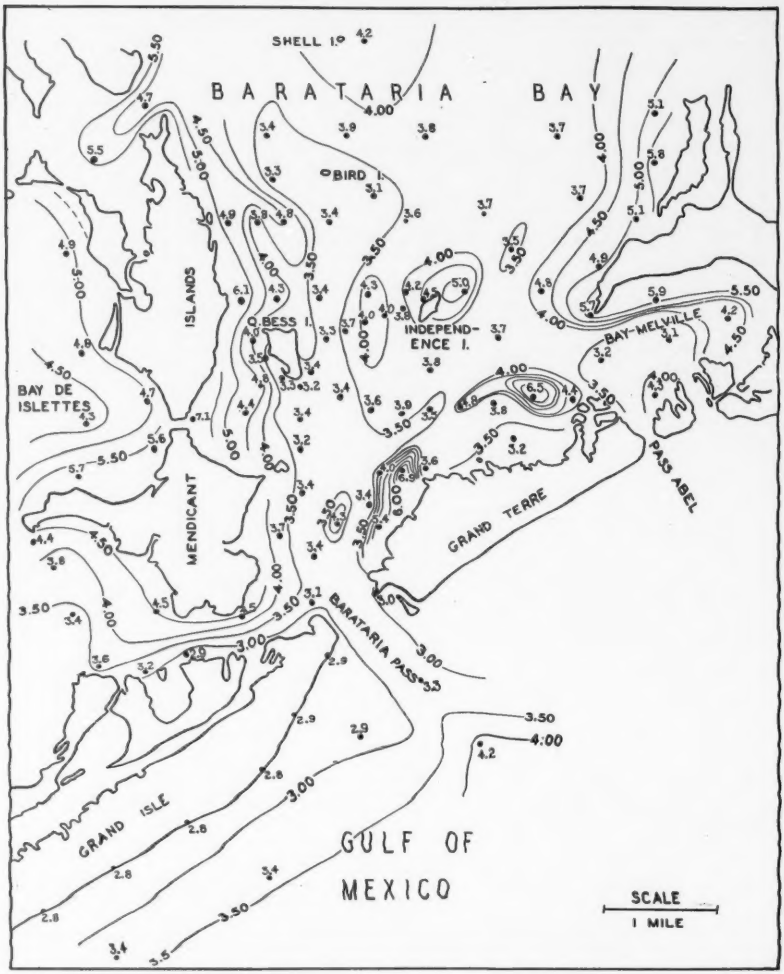

FIG. 5.—Phi-median map of the southern part of Barataria Bay.

Grand Terre, just northeast of the main Barataria Pass.

This general pattern, touched on in its broadest aspects, suggests very clearly that size is a function of the currents within the bay, inasmuch as the most appreciable currents move in and out of Barataria Pass, and sweep northward and southward between the two islands. The

present study did not include measurements of the currents within the bay, but some light may be obtained on the matter by considering the depth contours of Figure 2. It will be noted that the channels agree quite well with the size isopleths; and this feature attests to the selective action of the tidal currents that sweep in and out of the passes.

In detail one may note certain discrepancies between the zones of coarsest sediment and the actual channels as shown on the depth chart. Thus the 3.50 channel on the isopleth map swings between Queen Bess and Independence Islands, but is displaced to the west with reference to the actual channel in the bay. It was also mentioned that in general the average grain size decreases toward the shores. There is at least one conspicuous departure from this rule: the 3.50 isopleth just north of Grand Terre, and the 3.00 isopleth along the northern part of Grand Isle. Here clearly the average grain size increases toward the shore and indeed in the latter case masks the channel effect between Grand Isle and the Mendicant Islands. An examination of the barriers disclosed a fringe of sand dunes along the southern shore, and a veneer of wind blown sand back to the bay itself in many places. During strong off-Gulf winds sand is blown across the barriers and into the lagoon behind. It is to such occurrences that the writers attribute the size relations on the bay side of Grand Isle and Grand Terre.

In a broad way, however, we may picture an environment in which periodic currents sweep the material back and forth, leaving, perhaps, a lag sediment within the most pronounced channels, and selecting out the finer material, which is disseminated throughout the bay by slow drifts. Likewise the organic matter that tends to accumulate in the bay is swept out of the channels and is moved over to regions of quieter water where it is deposited with the finest sediments. On the other hand, it is possible that during storms strong currents sweep the channels clear of loose material, and locally expose the finer deltaic sediments[3] which presumably form the foundation of the more recent tidal lagoon deposits. It is interesting to note also that the isopleths show "shadow zones" of finer sediments at the edge of the main channel, and behind some of the islands. The pronounced "shadow" to the east of Barataria Pass appears to be due to slow reverse currents generated alongside the principal movement within the main channel. Such reverse currents seem to be the rule in tidal inlets.

The writers are pleased to report that Miss Winston's previous study of the same general region lead her essentially to the same conclusions as those above. Miss Winston noted and reported that the coarser sediments are in the channels of the bays, whereas the finer sediments are found nearer the islands. These variations are attributed by Miss Winston to the operation of tidal currents.

Figure 6 is a phi-deviation map, based on the data in the last column

[3] Notice, for example, the small area of finer material in the main channel just north of Barataria pass, in fig. 2.

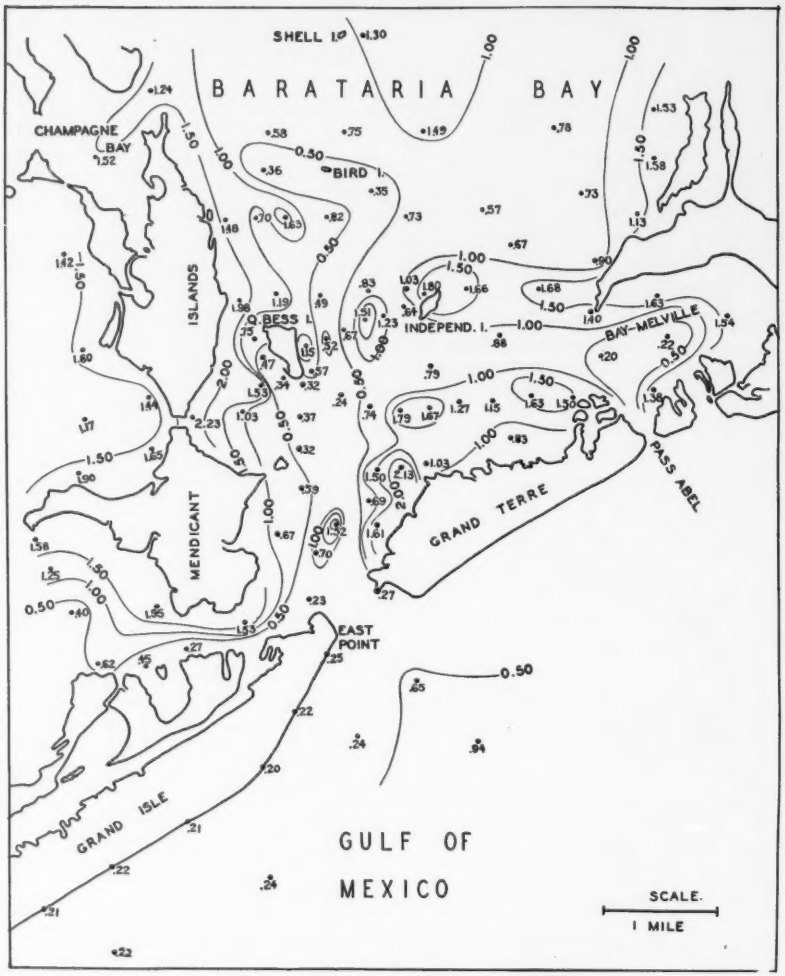

FIG. 6.—Phi-deviation map of the southern part of Barataria Bay.

of Table 1. The phi-deviation (QD_ϕ) is a direct measure, in Wentworth grades, of half the spread between the first and third quartiles. (See second reference in no. 2 of references for details of this measure.) The larger the value of QD_ϕ, the greater the spread, and hence the poorer the "sorting." The map accordingly shows the areal variation of the "de-

gree of sorting" of the sediments. A comparison with Figure 5 shows that as the average size decreases, the "sorting" also decreases. The general pattern of the two maps is similar, although there are differences in detail. It was necessary to postulate a well-sorted zone between Queen Bess and Independence Islands, to account for the well-sorted sediments to the north of these islands. On the whole, it seems safe to conclude that the same environmental factors that control average size also control the spread of the curves, so that in Barataria Bay there appears to be a definite relation between average size and the "degree of sorting" of the sediments.

SUMMARY

The present paper demonstrates that a study of the size characteristics of sediments affords some data for evaluating the physical conditions of the environment in which they occur. It also indicates that within a single environment there may be a wide range of sediments, so that it is necessary to examine a large number of samples before it is possible to evaluate the environment as a whole. The suggestion is strong that in the case of ancient sediments some notion of the environmental "pattern" may be obtained from a detailed study of the size distributions within a given area. Finally, the study demonstrates the futility of collecting one or two random samples from such a tidal lagoon, and from the histograms attempting to demonstrate the origin of the deposit. In many environments there may be a sufficient deviation from average conditions to afford some samples not unlike those found in entirely different environments, but when the areal distribution of sediment characteristics is studied, the chances appear to be in favor of distinctive "patterns" that may aid in identifying particular environments.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 1, PP. 18–30, FIGS. 1–8, TABLES 1, 2, 3, APRIL, 1937

A STUDY OF THE EFFECTS OF WIND TRANSPORTATION ON GRAINS OF SEVERAL MINERALS

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ABSTRACT

The facts and figures concerning the rate at which common rock-forming minerals are rounded and reduced by air transportation are meager and indefinite. The results presented here are quantitative, and it is hoped that they will encourage further work along the same line.

ACKNOWLEDGMENTS

The many authors dealing with the characteristics of wind-transported sediments are thanked for the information imparted through their papers. The papers of J. A. Udden, C. K. Wentworth and J. J. Galloway have been especially helpful.

The problem was first suggested by Prof. H. O. Whitnall and carried out by Mr. Paul S. Marsland under the direction of the senior author of this paper. Dr. David W. Trainer, Jr. has helped with suggestions and criticisms in the work.

The senior author takes full responsibility for errors which may appear in this paper.

THE PROBLEM

The problem was of a two-fold nature: (1) to determine the rate of rounding of some common rock-forming minerals when subjected to the abrasion of wind transportation, and (2) to determine the rate of reduction in size of the mineral grains transported.

Geologists have written and spoken rather freely for a long time of the characteristics of wind-blown sediments. Some few have tried to ascertain facts. Following the trend of recent workers in sedimentation to obtain data of a quantitative nature upon which we can depend with a certain degree of confidence work on the problem stated above was started.

MINERALS SELECTED

The minerals used in the experiment are listed with some of their properties (1) for the convenience of the reader. These minerals were selected because (1) they are frequently found in natural sands, and (2) they have a range in hardness convenient for comparison.

Nearly pure samples of the minerals were picked out and massive chunks of them were reduced in size by crushing with an iron mortar and pestle. This produced extreme angularity of the pieces. A circular and rubbing motion of the pestle rather

than just pounding was used to keep the amount of material reduced to a powder at a minimum.

The material was separated into size-grades by sieving. That which passed through the 1.16 mm. screen and was caught on the 0.991 mm. screen was used for the experiment. This was as near to the 1 mm. size-grade as could be obtained by the method and screens used. The different minerals were believed to have similar distributions between these limits. The 1 mm. size was selected because it represented the upper limit of material usually carried freely by winds (2) and was large enough to permit the measurement of angularity of the individual pieces.

It was thought that an equal number of particles rather than an equal weight of each mineral would give a more accurate comparison of their relative rates of wear. Therefore, 20 cubic centimeters of each mineral were used in each test.

TABLE 1. *Minerals used*

	H.	Sp. Gr.	Cleavage	Crystal System
Gypsum	1.5–2.	2.31–2.32	(010) eminent	Monoclinic
Calcite	3	2.71	(1011) perfect	Hexagonal (rhombohedral)
Apatite	5	3.17–3.23	(0001) imperfect	Hexagonal (pyramidal)
Magnetite	5.5–6.5	5.168–5.180	indistinct	Isometric
Orthoclase	6	2.57	(001) perfect (010) less perfect	Monoclinic
Quartz	7	2.653–2.66	indistinct	Hexagonal (rhomobhedral-trapezohedral)
Garnet	6.5–7.5	4.25	None (Parting distinct)	Isometric

APPARATUS

The problem of making suitable apparatus was attacked. It was necessary to have a current of air strong enough to support and hurl particles of 1 mm. in size at a considerable velocity. It was important that the direction of the particles be controlled and that they be kept in nearly constant motion.

An electric motor with a fan attached was taken from an old Hoover vacuum cleaner and used to supply the current of air.

Some experimenting was necessary to determine the size and shape of the air-chamber to be built around the fan and also the proper placing and size of the outlet. Several models of cardboard and tin were constructed before the one giving the desired air current was developed. The final result of the search for proper apparatus is pictured in Fig. 1.

In order to keep the particles in constant motion and also to have them convenient for observation, it was decided to have a glass tube, 1 inch in diameter, blown into the shape shown in Fig. 2.

Since some of the minerals were harder than glass, etching of it seemed inevitable. Pyrex glass was used as it is a little harder than ordinary glass and lasts longer. Possibly a better material could have been used for making such a tube but the

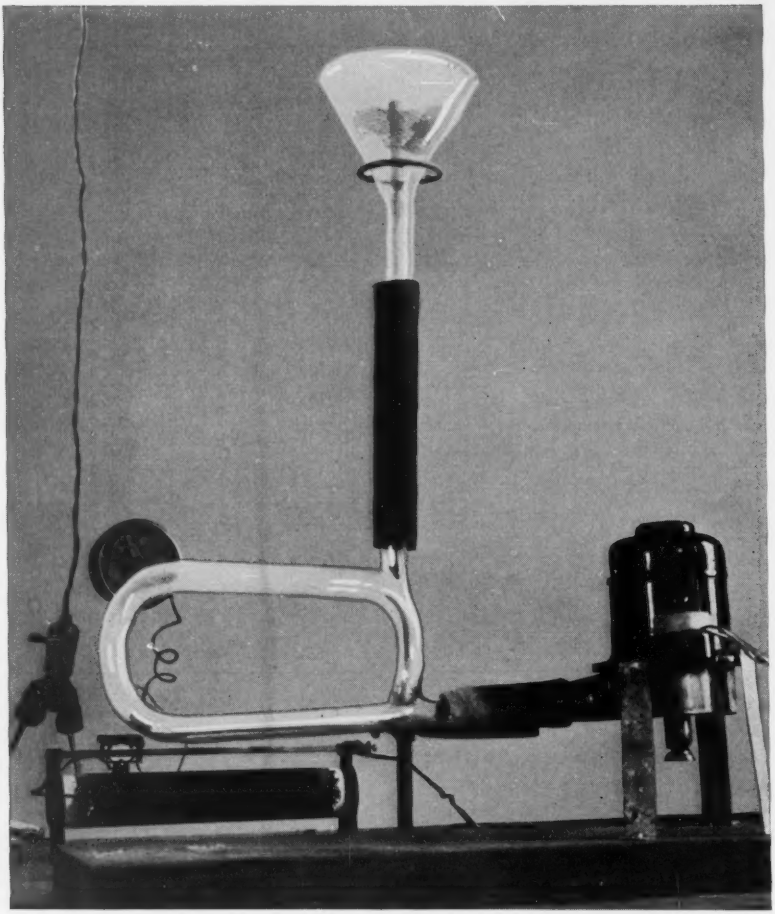

FIG. 1.—Apparatus used in this study.

factors of visibility, inexpensiveness, and ease of replacement seemed sufficient reasons for its use. The glass tube proved to be very satisfactory, and was etched by the blown grains of the minerals at only one place, at *C* in Fig. 2.

It was realized that a current of air could not blow through the tube at any greater velocity than it could escape from it. The outlet had to be placed at a point which would not interfere with the constant motion of the load carried by the air current.

The vent, although strategically placed, was found to be not entirely effective. While the air current was in operation many of the particles were suspended in the funnel-shaped vent.

To overcome this objectionable feature, which favored some particles by lifting them into the vent, the motor was shut off at regular intervals, which allowed the suspended particles to drop to the bottom of the tube. First, an electric-light flasher, commonly used for flashing Christmas-tree lights, was used to cut the current. It functioned irregularly and made it difficult to record the exact time when the air current was in operation. Then an electric clock was used to break the current. The second hand was employed to make contact so that the motor would run for 55 seconds and shut off for 5 seconds, thus allowing the particles to drop to the bottom of the tube. This arrangement gave much less liklihood of some particles being protected from the wear of transportation.

The magnetite particles were more than twice as heavy as the gypsum particles and the weights of the grains of the other minerals varied to a lesser extent. It was desired that the different minerals be transported through the glass tube at about the same velocity. A rheostat was put into the circuit to control the speed of the motor. The velocities used were such that the amount of material temporarily at rest at B, in Fig. 2, was approximately the same for each mineral.

Another problem was confronted. How were the lighter and smaller particles to be prevented from being lost through the funnel-shaped vent? A piece of galvanized screen wire was placed in the funnel to check the motion of the suspended particles. Several thicknesses of cheesecloth were placed over the top of the funnel to minimize the loss of the very

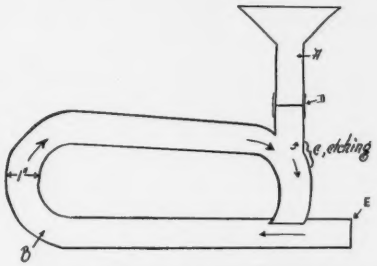

FIG. 2.—Glass Tube. (A) Funnel-shaped vent; (B) amount of mineral grains was constant at this place; (C) area etched by the impact of mineral grains; (D) rubber hose attaching vent to tube; and (E) point of attachment to Hoover fan.

fine particles. A sieving screen may be used to control the size of particles allowed to escape.

The mean volocity of the air current used was about 35 miles per hour. This was calculated from the wind pressure exerted in the tube. It was realized that this was much higher than the average movement of air currents on the earth's surface, but it was found convenient for use in the experiment here described.

A delineascope was used for projecting the images of the grains upon a screen. The images were then photographed for the illustrations in this paper. The pictures were

taken in a dark room with a Graflex camera. The exposures were 5 seconds.

RATE OF ROUNDING

One of the principal objectives of the experiment was to ascertain the amount and relative rates of rounding of the several common minerals used when subjected to eolian conditions of erosion. The experiment does not reproduce the conditions of eolian wear in all respects but it does give some data directly dependent upon air transportation.

It was thought that a simple mathematical expression of the degree of roundness attained would be the best method to record the results for comparison with other similar studies. An adaptation of the method used by C. K. Wentworth in measuring the roundness of pebbles was decided upon as being the most practical and suitable method for our purpose.

In measuring the roundness of pebbles, Wentworth uses, "the roundness ratio, r_1/R, in which r_1 is the radius of curvature of the sharpest developed edge and R is the mean radius of the pebble." "The reasons for the choice of r_1, and R as defined are apparent when it is considered that the largest value which the radius of curvature of the sharpest edge of any piece can have is the radius of the piece, and the limiting condition is that where $r_1 = R$—that is, the piece is a sphere, and the value of $r_1/R = 1$. The value of r_1/R always lies between 0 and 1" (3).

The grains are classified as angular, subangular, subround, and round according to the following scale:

Round	0.5– 1.00
Subround	0.175– .50
Subangular	0.075– .175
Angular	0.00 – .075

Wentworth obtained his measurements on pebbles by use of a gauge. Obviously a gauge could not be expeditiously employed to measure the angularity of anything as small as sand grains of 1 mm. and less in diameter.

The method here used was to project the images upon a screen by means of the delineascope and trace the profiles of the grains upon a piece of paper. The magnification thus obtained was twenty times the natural size.

While there is a valid objection that the measurements were taken in only two dimensions instead of three, yet this objection is largely offset by the greater accuracy obtained because of the magnification of the angles of curvature. The error would tend to be a greater angularity since the pieces would rest most generally upon their flattest side. The large number of grains measured in this way tends to decrease the error. Twenty grains were used for each measurement of every mineral.

In determining the radius of curvature of the sharpest edge and the mean radius a pair of dividers was used and the curves drawn on the profiles of the grains. The radii were measured in millimeters. The mean radius was derived from three measurements: the radius of the edge of greatest curvature, the radius of the edge of least curvature, and the

radius of an edge of estimated average curvature. It was thought that by using the three measurements of curvature rather than just those of greatest and least curvatures, a more accurate mean curvature would be obtained. When the grains had a concave surface the concavity was not measured in determining the degree of roundness.

All of the grains were angular before they were placed in the tube and blown. Their degree of roundness has arbitrarily been placed at 0. The shapes of the typical grains of each of the minerals used are shown in Fig. 3. It can readily be seen that only in the case of gypsum does the shape appear to have been greatly influenced by the crystal habit of the minerals.

FIG. 3.—Initial shapes of typical grains.

Each of the minerals selected for the experiment was transported by air in the glass tube for ten hours. At intervals of one hour each several grains were removed from the tube and examined with a microscope for evidence of abrasion. Where the evidence was considered to be positive, about twenty grains were photographed for comparison with other stages of the run. This comparison is shown in the figures.

A brief discussion of the effects of air transportation on each of the minerals is given below.

GYPSUM

Gypsum, as was expected because of its extreme softness, attained the greatest degree of roundness of any of the minerals used. Fig. 4*a–f* shows readily the rapid rounding of the grains of the mineral.

The gypsum grains were rhombic in shape before being placed in the blower, but many of the grains had jagged points and sharp edges.

After one hour of transportation the jagged points were worn down or broken off and the sharp edges were somewhat rounded. The rhombic shape was not noticeably affected.

After five hours the sharp corners and edges had become more nearly round. The rhombic shape was still evident. Frosting on the surface of the grains was noticed for the first time.

After seven hours little change was noticed except a slight decrease in size and an increase in the amount of frosting.

After ten hours, or at the end of the run, the grains showed a marked decrease from their original size. The rhombic shape had been replaced by a roughly ellipsoidal one of fairly high eccentricity. Corners or edges had become well rounded.

Mathematically expressed, the degree of roundess of the gypsum had progressed from 0 to 0.084 after five hours of transportation, or the grains had changed from angular to subangular in shape. The extremes of the grains measured were from 0.030 (angular) to 0.265 (subround). The grains at the ten-hour stage had attained an average roundness of 0.134.

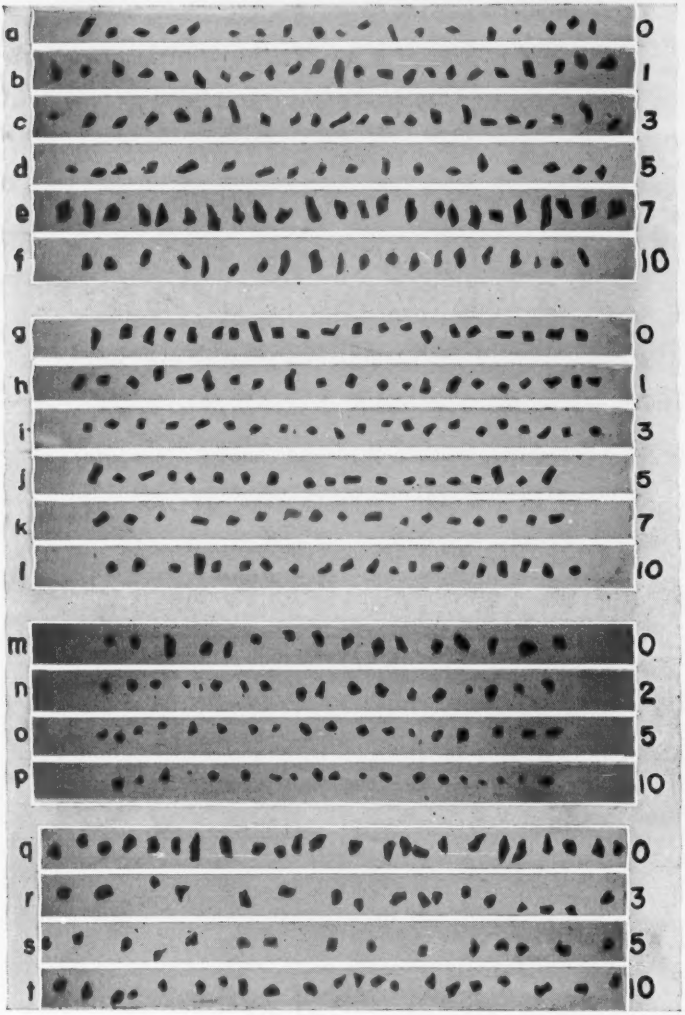

FIG. 4.—Photographs of mineral grains showing degrees of rounding (figures indicate number of hours of blowing; *a–f*, gypsum; *g–l*, calcite; *m–p*, apatite; *q–t*, magnetite.

This would place them approximately half-way between the subangular and subround classes. The rate of rounding was far less for the second five hour period than for the first. This decrease in rate of rounding probably continues as sphericity is approached. Figure 5 shows the curve for the two five-hour periods.

CALCITE

Calcite, the mineral next in softness to the gypsum used, showed an appreciable rounding but not as much as the gypsum. It is shown in its various stages in Fig. 4 *g–l*.

Only a few of the calcite grains showed typical rhombohedral shape and many appeared nearly cubical. The angles formed by the corners and edges were sharp and well defined. Some grains showed small projections which destroyed their symmetry.

After one hour of transportation there was only slight evidence of wear, as most of the sharp corners and edges were intact.

After three hours the sharpness of the corners had disappeared. A slight frosting on their surfaces was observed.

It was not until the end of the five hour run that the grains showed sufficient abrasion to warrant a measuring of their roundness. The average of the rounding was 0.073 or almost to the subangular class. The extreme measurements at this stage were from 0.038 (angular) to 0.122 (subangular). Ten of the twenty grains measured were angular and ten were subangular. The corners showed better rounding than the edges.

The seven hour sample showed little change from the five hour sample other than a little more frosting and a slight decrease in size.

At the end of ten hours the calcite showed an average roundness of 0.109. The extreme range of the grains measured was from 0.04 (angular) to 0.322 (subround). The decrease in size of the grains was not as striking as in the case of gypsum.

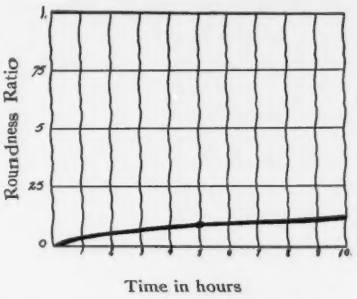

FIG. 5.—*Curve showing the decrease in rate of rounding.*

APATITE

The apatite used gave some surprising results. It was noticed that when the apatite was crushed it seemed to pulverize easily for a mineral of its hardness. Microscopic examination showed many parting planes. Fig. 4 *m–p* shows the apatite grains in various stages of abrasion.

After only two hours of transportation the apatite showed a marked decrease in the size of the grains and an increase in the number of smaller pieces in the tube. While some of the

corners and edges were distinctly abraded, there were many corners and edges showing no abrasion. All of this seemed to be due to the good parting shown by the apatite.

Five hours of wear showed an increase of the above mentioned phenomena and fairly good rounding of the corners and edges.

After ten hours of transportation the grains were measured for roundness and it was surprising to find that they had been rounded as much as the calcite. The average roundness ratio was 0.109 with extremes ranging from 0.044 (angular) to 0.199 (subround). The grains had all of the corners and edges rounded and were more frosted than the calcite.

MAGNETITE

The grains of magnetite showed no characteristic shape. Conchoidal fracture and sharp points were distinctive features (Fig. 4 *q–t*).

Only a slight change was noted in the magnetite at the end of the three hour run. The sharp points had become blunt and the edges showed slight rounding.

Five hours of blowing showed a little more wear upon the corners and edges. One or two grains were noticed that had progressed past the angular stage, no doubt made possible by a favoring original shape. The remainder of the grains were quite angular.

Measurement of the grains after ten hours of blowing gave an average roundness ratio of 0.084, or barely within the subangular classification. The extremes were 0.027 (angular) and 0.204 (subround). Most of the grains had the corners and edges rounded but a few only had the sharp edges dulled.

ORTHOCLASE

The orthoclase grains had no characteristic shape, with the possible exception that many of them had one long dimension. They are shown in Fig. 6 *a–c*.

After ten hours of wear the orthoclase showed little apparent change. The corners had been slightly rounded and there was a very small decrease in the size of the grains. They were still decidedly angular. The degree of roundness approximated 0.02.

QUARTZ

The quartz grains (Fig. 6 *d–f*), showed very sharp points and jagged edges.

After ten hours, the only evidence of abrasion was the wearing off of some of the sharpest points. The angularity of the grain approached 0 and has been given a liberal approximation of 0.01.

GARNET

The grains of garnet were very irregular in shape, as shown in Fig. 6 *g–i*.

Garnet, the hardest of the seven minerals used, very surprisingly, showed a much greater degree of rounding than either the orthoclase or the quartz.

Measuring the grains after ten hours in the blower gave an average roundness ratio of 0.061 or near the subangular class. The extremes of roundness were 0.021 (angular) and

0.095 (subangular). All of the grains showed some abrasion.

CLASS DISTRIBUTION OF GRAINS

The following table shows the distribution of the grains into the roundness classification used. They represent twenty grains selected at random from each mineral sample after ten hours of blowing.

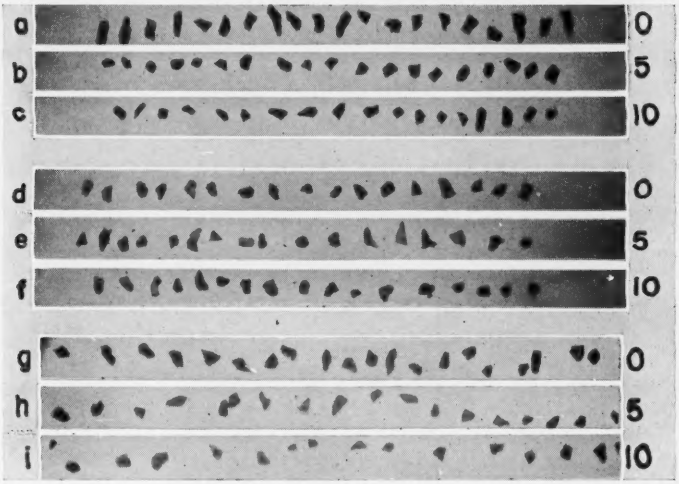

FIG. 6.—Photographs of mineral grains showing degrees of rounding (figures indicate number of hours of blowing); *a–c*, orthoclase; *d–f*, quartz; *g–i*, garnet.

TABLE 2. *Distribution of the grains in the roundness classification*

	Angular	Subangular	Subround	Round
Gypsum	4	14	2	
Calcite	9	10	1	
Apatite	4	14	2	
Magnetite	8	11	1	
Orthoclase	20			
Quartz	20			
Garnet	14	6		

This table may be misleading, for it must be remembered that the average rounding of the gypsum was 0.134 as compared to 0.109 for the apatite. Even though they have the same grain distribution according to the classification used, the variation within the classes accounts for the difference. This discrepancy indicates the advantage of numerical values over class distribution for comparison.

Below is a table showing the comparative roundness attained by the minerals tested at the end of the ten hours run. The values given the orthoclase and the quartz are estimates.

TABLE 3. *Comparative roundness of minerals after 10 hours run*

Gypsum	0.134
Calcite	0.109
Apatite	0.109
Magnetite	0.084
Orthoclase	0.02*
Quartz	0.01*
Garnet	0.061

* Estimates

REDUCTION IN SIZE GRADE

The second objective of this experiment was to determine the amount of reduction in size of the minerals used.

The material selected for the tests was passed through a screen with 1.16 mm. openings but was retained on a 0.991 mm. screen, after shaking for about five minutes.

After ten hours of being blown, the remainder of the original 20 cc. of each mineral was separated into size grades by the use of standard screens. The screens used were the following:

Approximate size	Diameter of openings
1 mm.	0.995
½ mm.	0.495
¼ mm.	0.246
⅛ mm.	0.124
1/16 mm.	0.061

Because it was believed that most of the material would be caught upon the 0.495 mm. screen, it was decided to split this size-grade by the use of screens of 0.833 and 0.701 mm. openings.

The results of the size-grade analysis have been placed in graphs for convenience of comparison. The upper areas of the graphs represent the percentages of these sizes graded by the standard screens. The horizontally lined areas represent the size-grade distribution of the material caught on the 0.495 mm. screen, and split up by the 0.833 and 0.701 mm. screens.

The graphs show that grains of all of the minerals were reduced in size at the end of ten hours of transportation. The minimum loss from the original size-grade was 26.3 per cent for the garnet and the maximum was 97.2 per cent for the gypsum. With the exception of the apatite, the minerals show a regular decrease in the amount of loss in the 0.991 mm. size-grade as the hardness increases.

The explanation of the abnormal results given by the apatite is that the especially good and numerous parting planes of the apatite allowed much of it to break up into smaller pieces. It is noted that the ¼–½ mm. size-grade is larger than that of any of the minerals except the very soft mineral gypsum.

It was surprising that there was such a rapid decrease in the size of the grains of all of the minerals used, for the very short time which they were blown.

Following are the graphs (Figs. 7, 8) showing the size-grade distribution of the minerals after being subjected to ten hours of blowing.

CONCLUSIONS

It was found that there is a close relationship between the hardness of a mineral and its rate of being rounded by air transportation. This close relationship may be masked by other factors, such as parting, cleavage, crystal structure, original shape of the grains, etc.

The quantitative data indicates the rapidity with which wind-blown material is rounded and reduced in size.

It is believed that this experiment

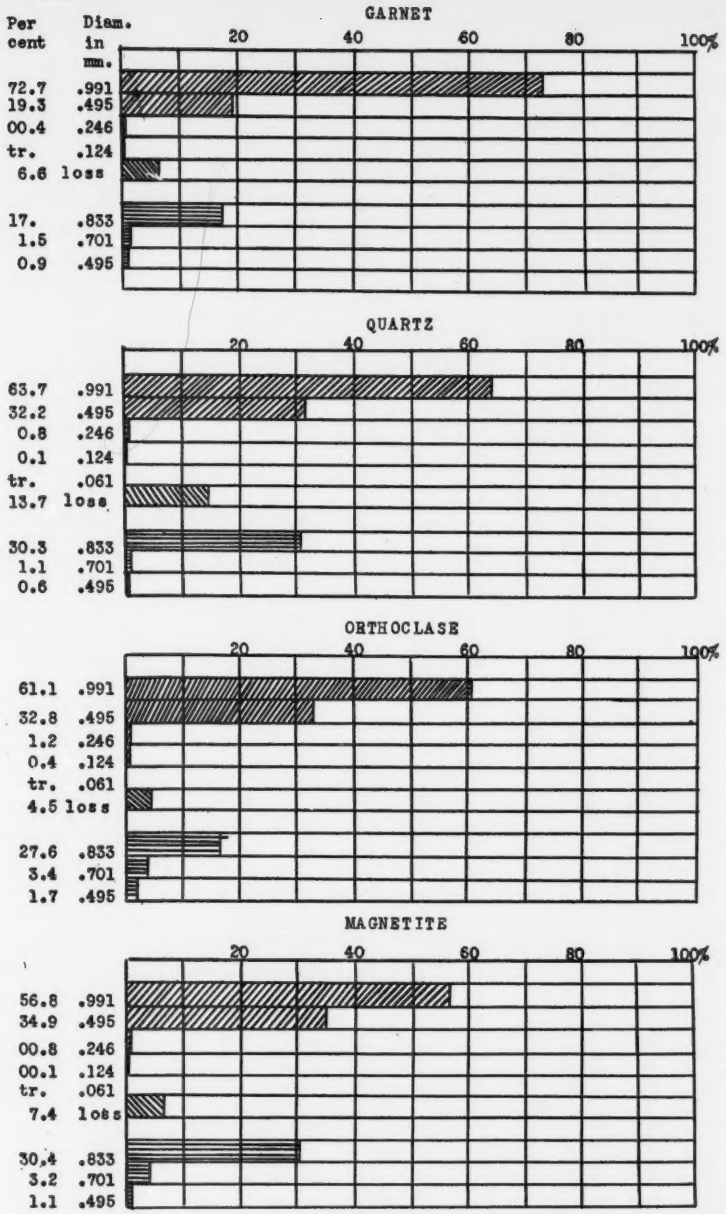

FIG. 7.—Graphs of size-grade distribution of garnet, quartz, orthoclose, and magnetite.

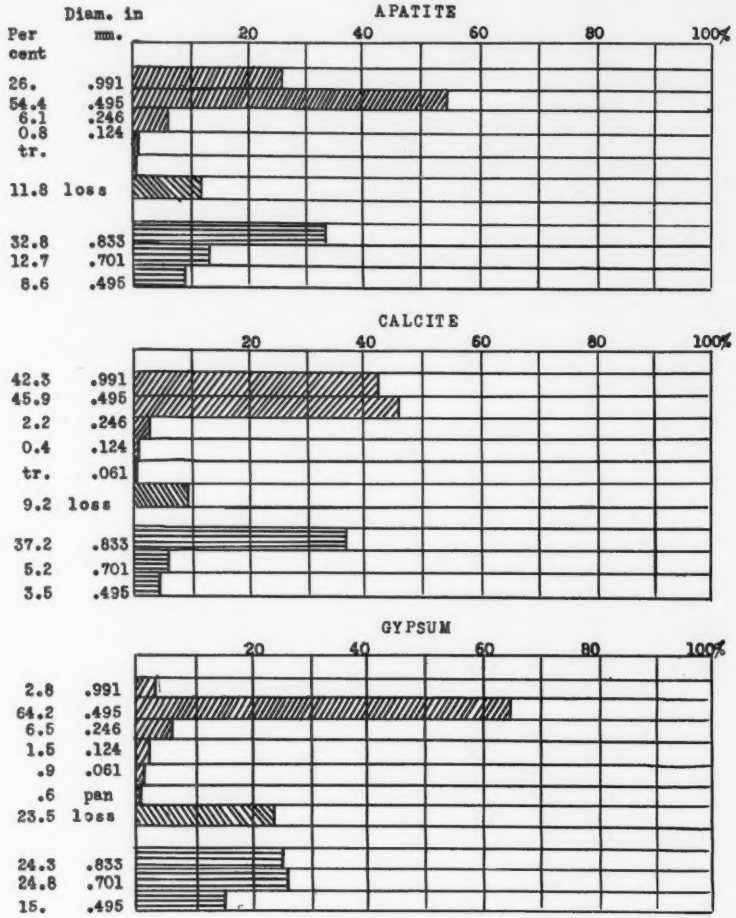

FIG. 8.—Graphs of size-grade distribution of apatite, calcite, and gypsum.

is a step in the right direction, and it should be continued over longer periods and with a wider variety of minerals. Further work is projected.

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3. WENTWORTH, C. K., The shapes of pebbles, *U. S. Geol. Survey, Bull.* 730-C.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 1, PP. 31–33, FIGS. 1–5, TABLE 1, APRIL, 1937

VENTIFACTS FROM NEW MEXICO

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ABSTRACT

New Mexico is added to the list of states from which ventifacts have been reported. The shapes, sizes, facet angles, and composing materials are described, also the various factors believed to be instrumental in forming ventifacts in the localities near Socorro.

A recent article by Wentworth and Dickey (1) lists the localities in the United States from which ventifacts, or wind-worn stones, have been collected or observed. Although 61 localities are listed from 19 states, none are cited from New Mexico. It is safe to say that ventifacts are not common over this state, even though large parts of it are windswept. It should be borne in mind that over much of New Mexico the wind is depositing its load or lifting it high into the air rather than scouring the pebbles lying on the ground. Only in a few favored localities are the several factors properly combined to bring about the formation of ventifacts.

Bryan (2) reports wind-cut stones from the valley of the Rio Puerco in the northern part of the state, but this locality has not been described in print. A locality near Socorro has been discovered in which ventifacts are very plentiful and well developed. It was discovered by Mr. Evan Just, a former member of the faculty of the New Mexico school of Mines, and the writer in 1931. It is about 10 miles northeast of Socorro on the floor of a small bolson known as the Valle del Ojo de la Parida.

This bolson extends nearly north-south and is trenched in one or two places by arroyos draining into the Rio Grande. The ventifacts are found at the extreme south end of the bolson. Triassic red beds and Cretaceous sandstones outcrop in the bolson; Pennsylvanian limestones and Permian red beds, limestones, and gypsum outcrop in the surrounding hills. The older rocks are overlain in places by a considerable thickness of gravels and sands, believed to be Pleistocene in age, derived mainly from Pennsylvanian and Permian limestones and Permian and Triassic red beds. Capping the Pleistocene deposits is a thin blanket of recent wash along with some wind-blown sand.

Sheet wash has loosened the pebbles from the Pleistocene gravels and deposited them on low terraces just above one of the small arroyos in the bolson. Quartz sand from the arroyos is available for scouring, but not enough is present to turn this part of the bolson into a place of deposition. It is obvious that the wind frequently has a high velocity along this narrow little valley, probably from the north and south almost entirely. Absence of vegetation on

the terrace adds further to the effectiveness of the wind.

The ventifacts are found to have different shapes, some retaining almost entirely the original shape of the water-worn pebble but showing some polishing by wind action. Many others have very highly polished surfaces, with only a suggestion of facets; occasional pebbles show excellent facets cut by the sand blast. Of the faceted pebbles, a few are to be classed as belonging to the ridge-shaped type in which two facets are inclined toward each other to form a ridge, and other facets may exist at one or both ends; however, the majority belong to the pyramidal type (3).

There is also considerable variation in size among the ventifacts. The smallest ones are slightly larger than beans; the largest is about 4 inches long. The majority are from 1 to 2 inches in diameter.

Nearly all the ventifacts from this locality are composed of quartz, quartzite, or hard sandstone; a few are composed of granite, hematite, or limestone. In general, the softer rocks in the vicinity tend to be cut away entirely rather than to become polished or faceted.

The angles made by the facets with the horizontal have different values, which fact is probably due to the original shapes and hardness of the pebbles, their positions on the ground, the length of time each face was exposed to the sand blast, and possibly to other factors. According to Wade (4), the facets on ventifacts make angles of 40° to 50° with the horizontal, usually near 45°. Schoewe (5) has shown by experiment that cutting by the sand blast may be rapid

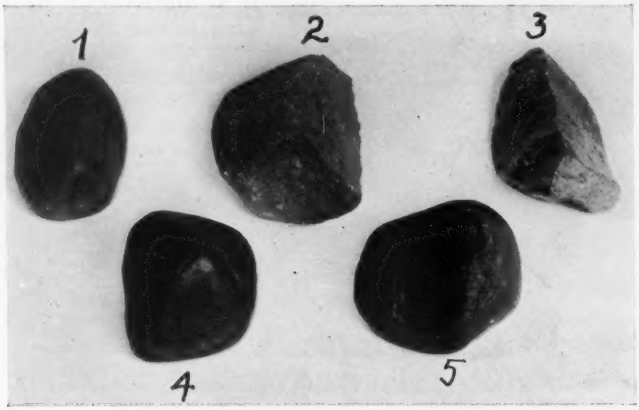

FIG. 1.—Ridge-shaped ventifact of quartzite.
2.—Dreikanter of limestone.
3.—Ridge-shaped ventifact of limestone.
4, 5.—Dreikanters of quartz.

where the face makes a high angle with the horizontal but is extremely slow when the angle becomes as low as 30°.

From his collection made near Socorro the writer selected 52 pebbles upon which were developed a total of 134 fair or good facets and measured the angles between the facet and the horizontal. The angles varied from a low value of 28° to a high value of 87°. The results are given below in tabular form.

TABLE 1

Angle of facet with horizontal (degrees)	Per cent
25–29	0.8
30–34	1.5
35–39	6.8
40–44	6.0
45–49	14.1
50–54	14.0
55–59	12.0
60–64	11.1
65–69	12.0
70–74	3.8
75–79	8.1
80–84	6.0
84–89	3.8

It is seen from this that for this particular locality pebbles having faces with high angles to the horizontal are worn down rather rapidly until values between 45° and 70° are reached, after which the cutting is so slow that only occasional pebbles are found with values below 45°.

It is seldom that the facets on a pebble all make equal angles with the horizontal. Generally, the angles vary among themselves from a few degrees to as much as 45° or 50°. A number of factors may be involved to bring this about, but it is likely traceable in large part to more persistent winds from one direction.

Ventifacts in central New Mexico are not confined to the Valle del Ojo de la Parida. The writer has found a number of good ones on the pediments east and southeast of Socorro. A few of the best ones are of limestone. On the whole, however, the pediments east of the Rio Grande are marked by wind deposition rather than by pronounced wind scour; therefore, good ventifacts are rare, although pebbles showing some wind polish are not uncommon.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 7, NO. 1, PP. 34–35, FIG. 1, APRIL, 1937

INEXPENSIVE EQUIPMENT FOR RECLAIMING HEAVY LIQUIDS

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In order to reclaim certain heavy liquids such as bromoform and acetylene tetrabromide, used in mineral separations, some liquid such as grain alcohol which is soluble in both the heavy liquid and in water is used to wash the mineral grains and filter papers after the separation has been completed. Water added to the wash mixture mixes with the alcohol, leaving the pure heavy liquid in the bottom of the container.

When many mineral separations are made the amount of wash consisting of the heavy liquid and its solvent is quite large. This means either using a number of separatory funnels or making a number of separations with one funnel if the supply of funnels is small. This is a time-consuming process because it requires three or four hours for the emulsion of water and wash mixture to break down. The necessity of repeating the procedure a number of times increases the time accordingly.

In order to eliminate this inconvenience in time and the use of expensive separatory funnels, the wash was put into two-liter reagent bottles. When the bottles were about one-fourth full of the wash, enough water was added to almost fill the bottle. A two-hole rubber stopper fitted with

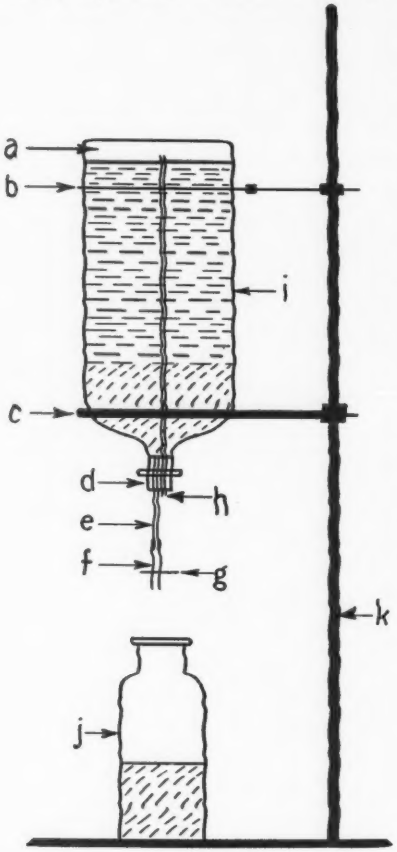

FIGURE 1

a—Air space left at the top of the bottle
b—Loop of heavy wire to hold the reagent bottle in position.
c—Ring of the stand.
d—Two-hole rubber stopper.
e—Withdrawal tube.
f—Rubber tubing.
g—Pinchcock.
h—Air tube.
i—Two-liter reagent bottle.
j—Stock bottle.
k—Ring stand.

glass tubes arranged as shown in figure 1 was inserted in the neck of the bottle which was then inverted and placed in a ring stand. A loop of heavy wire was placed around the upper part of the bottle to steady it in the ring stand. While inserting the stopper a finger placed over the base of the air tube prevents any of the emulsion from entering the tube and leaves the tube open to the passage of air. Also, a small air space was left at the top of the bottle when it was filled with water so that the air tube could function properly when the bottle was inverted.

After the emulsion had broken down and the separation was completed the heavy liquid was withdrawn from the bottom of the wash bottle into the stock bottle by opening the pinchcock attached to the rubber tubing at the base of the withdrawal tube.

REVIEWS

ESKIN, HENRY M., *Silting of Reservoirs*, U. S. Department of Agriculture, Tech. Bull. No. 524. 126 pp., Bibliography, Appendix, July, 1936.

Recent activities of the Soil Conservation Service (1934–'35) have given rise to this volume of information on the nature of silt accumulation in a series of representative reservoirs in the southeastern, south-central, and southwestern United States. The "ultimate objective of the studies is to accumulate information on the factors involved in the silting of reservoirs, including rates of silting, and to correlate the results with soil, slope, and climatic conditions and land use in watershed areas." The most obvious practical result anticipated is to establish a policy for reservoir construction and silt control, and incidental to this the report contains considerable data pertinent to sedimentation studies. Among the most useful data are: (1) the average annual rate of silting per unit of drainage area in the 3 regions studied, and (2) critical observations on the phenomenon of underflow in stationary fresh water bodies as it affects the distribution of sediment in the basin.

The bulletin is subdivided into several parts, of which the following are of most interest to geologists: (1) Economic and physical aspects of the problem in which attention is drawn to the distinction between natural ("geologic norm") and man-induced ("accelerated") erosion. The thesis of the bulletin is reforestation of the millions of acres thrown into submarginal agricultural land due to topsoil waste because of incorrect farming methods. (2) Processes of reservoir silting, in which the well-known laws of stream transportation are expanded. Several important points are added, however, which are doubtless often overlooked in the study of lake sediments. Namely, where the stream load contains a large percentage of coarse sediment and the basin is frequently at full stage the total load contributed by the stream to the basin is greatly reduced by "valley aggradation above reservoir level," i.e. by backward delta growth, and especially is this true when new vegetation on the delta acts as a sieve for inflowing streams. This arrest of sediment before it reaches the basin is obviously a factor in the prolongation of reservoir life. When only coarse sediments are carried into the basin, the volume of the delta constitutes the entire sedimentary accumulation, but when no appreciable coarse material is contributed, deltas are entirely lacking due, for the most part, (by the reviewer) to the absence of electrolytes in the reservoir water necessary to coagulate the colloidal materials.

The author cautions against assuming that the delta represents total sediment, and points out pertinent facts concerning underflow whereby great quantities of high gravity silt-laden waters are propelled far beyond the delta to form greatly extended silty bottom-set beds. He has found, for example, "that the volume of finer grained bottom-set beds, more frequently than otherwise, exceeds the total volume of delta deposits and that, contrary to customary thought, the depletion of deeper reservoir storage space in the vicinity of the dam may not await the gradual approach of growing deltas but may, and in most cases, does begin at selective rates from the very beginning of storage." In the extreme case of the flooded Puerco River, carrying up to 15% of solid matter into the Elephant Butte Reservoir (New Mexico), the rate of underflow has been computed at "over 2 feet per second, or about 1½ miles per hour." Muddy underflows, it is stated, have repeatedly passed through outlet gates in dams when surface waters were crystal clear, and repeated observations of this type lead to the conclusion that "stratification of different density liquids" is determined by variable silt content of inflowing waters. This gives a clue to the interpretation of many ancient silty and clayey lake deposits, and doubtless similar principles will apply where streams empty their silty and colloidal load into salt water. The mode of origin of the widely distributed laminated shales, such as the black shales of the upper Paleozoic have always been puz-

zling. (3) Previous investigations. One measurement will suffice to show the character of the data presented. The dam at Roosevelt Reservoir, Roosevelt, Arizona, was completed March 18, 1911. In 1925 a survey showed "a total accumulation of 101,000 acre-feet of sediment, predominantly . . . coarse-grained." This gives an average annual rate of 116.9 acre-feet a year per 100 square miles of drainage. A similar survey in 1935 showed a total of 108,800 acre-feet, or 7,800 acre-feet accumulation in 10 years. (4) Reservoir surveys by the Soil Conservation Service in 1934–35. Under "Methods of Survey" two immediate objectives are set forth: (1) "To measure . . . the total volume of sediment accumulated to date, its relative distribution, its ratio to capacity and age of the reservoir, and to size of drainage area"; and (2) to establish a system of fixed points ("monuments") as a basis for future comparison.

Space will not permit detailing the methods of survey used or the clever new tool, called a "spud," invented by the author's party, and used for measuring silt thicknesses. Fourteen reservoirs were studied, 5 in North Carolina, 1 in South Carolina, 1 in Georgia, 3 in Texas, 2 in Oklahoma, 1 in New Mexico and 1 in Arizona. The highest annual silt accumulation per 100 square miles of drainage area was found at Rogers, Texas. Here 569 acre-feet accumulated annually, as compared with 236.37 acre-feet at Guthrie, Oklahoma; 205 at Concord, N. C.; 26.55 at Durham, N. C.; 68.54 at Hot Springs, N. Mex.; and 43.05 at Coolidge Dam, Arizona. Considering differences in rainfall, type of vegetable cover, and character of bed-rock in the several regions these figures become intensely interesting and significant to the sedimentationist.

The bulletin also records a few reconnaissance investigations.

In summary, the author concludes that "in the Southeast, reservoir silting results chiefly from erosion of deep residual soils as influenced by human occupation." Lower rates obtain where the natural forest cover is practically intact. Higher rates go with unwise farming practices. "In the southern Great Plains higher rates of silting relate to erosion of sedimentary soils under agricultural and grazing practices." "In the Southwest higher rates of silting are largely the result of overgrazing. . . ."

The bibliography of 19 items contains 12 not commonly consulted by geologists.

The Appendix is a valuable set of instructions for reservoir sedimentation surveys, describing all methods used and it also contains useful formulae for calculating amount of silt, volume of delta deposits, original capacity, etc. A system of note keeping is also outlined.

Aside from the value which this bulletin holds for students of sedimentation there is ample reason to recommend it to the engineering geologist.

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Robinson, G. W., *Soils, Their Origin, Constitution, and Classification*. London, T. Murby and Co., 2d edition, pp. 442+5 plates and 17 figs., 1936. 20/0 net.

Sedimentary petrologists as a class have not considered soils as part of their province of study. This probably arises from the fact that in reconstructing the environment of transportation and deposition, it is desirable to have fresh, unaltered samples of rock. And yet, from a broader point of view, the sediments themselves are largely derived from earlier material that has passed through the weathering cycle. Furthermore, one cannot always be certain that a given sample has not been affected by changes akin to weathering during some stages subsequent to deposition, and it would be desirable to have some criteria for determining this fact. By and large, it would be advantageous for sedimentary petrologists to pay more attention to the weathering phenomena of sediments, and the effects of such phenomena on the mechanical, chemical, and mineralogical composition of sediments.

An excellent book for the purpose of becoming acquainted with the field of soil science (pedology) is Professor Robinson's book. The second edition of this work has recently appeared, and should be read by every student of sediments. The author devotes the first half

of his book to a review of the many factors involved in the soil forming process, including such topics as weathering, the clay complex, base exchange (a fertile field practically ignored by sedimentary petrologists), soil organic matter, and the water relationships of soils. The reader of this first half of the book will find many suggestions for lines of research that have a direct bearing on purely sedimentary problems. A sediment that has been weathered is still a sediment, and in many cases it may be desirable that a study of the deposit should include its weathering as well as its transportation and deposition.

The last half of Professor Robinson's book is devoted to the main soil groups—the podsols, the tshernosems, saline soils, tropical soils, and the like. Here is a wealth of informative material that may well be part of the general knowledge of sedimentary petrologists. The volume closes with a discussion of soil classification and world soil distribution. The book is well organized, the material is lucidly presented, and the chapters are supplemented with selected bibliographies. The latter feature will prove an advantage for locating source material along lines of particular interest.

Repetition is justified: the volume deservedly should be read by sedimentary petrologists, and moreover, it belongs in every library of sedimentary petrology.

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Rutley's Elements of Mineralogy, 23d edition, London, 1936. Revised by H. H. Read.

The new edition of this well known English textbook of mineralogy has been enlarged and improved throughout. The chapters on crystallography and optic properties have been completely rewritten and a new chapter on occurrence of minerals has been added. The book has been increased 25 per cent in number of pages. In the descriptions of minerals the arrangement is an economic one based on the chief useful element in each mineral, the elements being considered in the order of the periodic classification.

The many editions through which Rutley's Mineralogy has passed abundantly prove that it gives a very satisfactory elementary treatment of the subject. It seems unfortunate that it is so sparingly illustrated (128 figures as compared with 360 in Dana's "Manual," 578 in Rogers' "Study of Minerals" and 812 in Kraus, Hunt, and Ramsdell's "Mineralogy") and that the new conceptions of the constitution of minerals are not recognized (for example, amphiboles are described as anhydrous).

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HAGERMAN, TOR, H., *Granulometric Studies in Northern Argentine*, with a short chapter on the regional geology of central South America. Geografiska Annaler, Vol. 18, pp. 124–213, 7 plates, 1936.

This work consists of two chapters, in the first of which is given a brief review of the regional geology of central South America. The second chapter gives the results of the studies of the quartz particles composing some of the sediments in the region of northern Argentina. The studies were made in the interest of development of the oil industry of northern Argentina. The second chapter gives methods of study and the results of the statistical study of six stratigraphic units. The studies emphasize the importance of relative width of quartz particles and maximum grain size variation.

The author uses a term which the reviewer has met for the first time. This is "*granulometric*" *horizon*. The term is not clearly defined but seems to represent "horizons of corresponding grain assemblage."

The work contains much of interest to the sedimentationist, but it is written in rather involved English so that in many places it is difficult to grasp the meaning and conclusions of the author.

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